

**The Use of Superabsorbent Materials
in Optical Fiber Cable Design**
C. John Arroyo, Jim J. Sheu, and W. J. Paucke
AT&T Bell Laboratories and Network Cable Systems
Norcross, Georgia 30071

The present global demand for optical fiber cables has required a reevaluation of present cable designs to insure quality in every aspect of cable design and manufacturing. In order to provide quality water-blocking capabilities in optical fiber cable sheaths, an investigation was initiated to study the prevention of water ingress and migration in cable sheaths. Tests were designed and/or modified to study the movement of water under pressure at different sheath interfaces. Superabsorbent materials in three different configurations were found to outperform other materials. As a result of this development, superabsorbents have been incorporated into all optical fiber outside plant cable sheaths, with consistent reliable performance.

INTRODUCTION

With the global increase in optical fiber cable demand, customers are requiring greater performance reliability, and zero maintenance at lower costs. The technology of preventing the ingress and migration of water inside cables has progressed from gas-pressurized systems to filling and flooding compounds. Gas-pressurized systems have difficulty providing long term reliability and the maintenance costs are prohibitive. Flooding compounds require the use of an organic solvent at termination. Another commonly used material is a 'sticky' atactic noncrystalline polypropylene flooding material. These flooding compounds are difficult to apply during cable manufacturing and are not craft-friendly during termination in the field.

An alternative and more efficient water-blocking provision has been accomplished by use of 'superabsorbents'. Developed in 1966 by the United States Department of Agriculture, and appropriately called 'Super Slurper', superabsorbents have been extensively used in the incontinent market.^[1] In 1975, superabsorbent laminated tapes were first offered in Europe for the cable industry, and in 1977, a

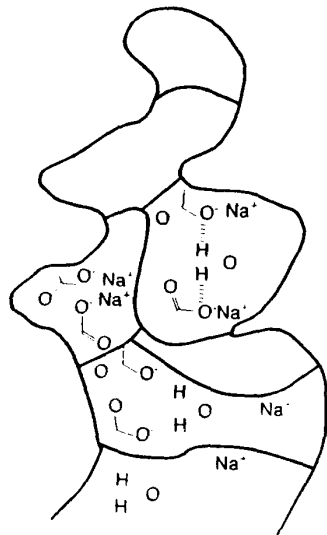
superabsorbent powder in loose form was first introduced into a copper cable design. Since then all major cable manufacturing companies have experimented and/or introduced superabsorbents in various forms into their cable designs. This paper will discuss the chemistry and application of superabsorbents in fiber optic cables.

SUPERABSORBENT POLYMERS

The significance of providing water-blocking protection in cables is to eliminate the possibility of water entering the splice closure. In freezing environments, such an occurrence could induce microbending in optical fibers, resulting in fiber degradation or increased loss. One of the first documented uses of the term "superabsorbent" was by R. E. Erickson of Dow Chemical in 1980.^[2] A superabsorbent is a dry material which rapidly absorbs about 1000 times its own weight in distilled water to form a gel with a corresponding volume increase.^[1] While undergoing these changes, the material retains its original identity. This means that the basic chemical structure of the superabsorbent is not changed. Recently, J. R. Gross of Kimberly-Clark Corp.^[3] suggested a term "Xerogellant." The prefix "xero" means a dry material while gellant, contraction of gelling agent, describes the behavior of the material. The new term, although applicable to the incontinent market, is not general enough to cover materials produced in wet form, such as many water soluble polymers which can be crosslinked to produce superabsorbent polymers (Figure 1). For the cable industry, superabsorbent polymer (SAP) seems to be a more popular term.

The mechanism by which SAP absorbs and retains water can be described in two ways, physical and chemical. On the physical level, aqueous fluid wets the surface of SAP and is physically distributed into and throughout the network (or matrix) of SAP. Since the aqueous fluid is moving in columns of continuous fluid, the physical absorption of SAP depends upon factors such as pore size, specific gravity, viscosity, surface tension and contact angle. The last two factors actually affect the wettability of SAP.

Crosslinked Superabsorbent Polymers Figure 1



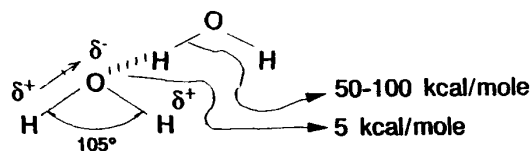
The other type of absorbency is chemical, which occurs on the molecular level. The aqueous fluid interacts with the polymer chains via solvation and hydrogen bonding. Since energy associated with this process is relatively high, the aqueous fluid has been described as "bond" water. The bulk of fluid chemically bonded to SAP does freeze with some difficulty but does not easily escape out of the network (matrix) of SAP.

The SAP at this stage look like gels, and are generally described as "hydrogels." Factors such as hydrogen bonding, hydration (solvation), diffusion, porosity of network, electrostatic attraction and repulsion affect the chemical absorption of SAP. Overall, if the matrix (network) of SAP is considered as a separated entity from the surrounding aqueous fluid, a pressure gradient can exist between the two entities. Physically, such a pressure gradient is in effect an osmotic pressure gradient. This is why people attribute the absorbency of SAP to osmotic pressure.

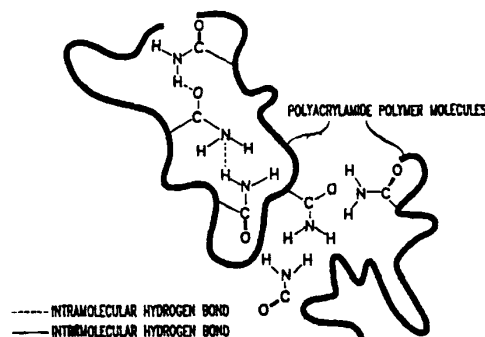
Whether the SAP absorb aqueous fluid via a chemical an/or physical process, the most important driving force for these processes appears to be the high energy hydrogen bonding. In water, the energy for hydrogen bonding has been found to be about 5 k cal/mole (Figure 2). This energy is very significant considering the very strong covalent bond energy of 50-100 k cal for the O-H bond in water. Furthermore, there are numerous hydrogen bonds among the superabsorbent molecule and water molecules.

Figure 2 HYDROGEN BONDING (H-BONDING)

A Hydrogen Atom Serves as a Bridge between Two Electronegative Atoms, Holding One by a Covalent Bond and the Other by a Purely Electrostatic Forces



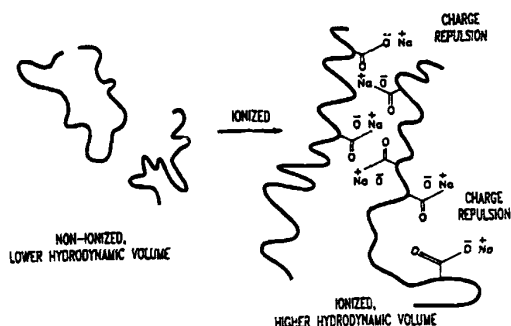
- Special kind of Dipole-Dipole Attraction



Hydrogen Bonding of Polyacrylamide Figure 3

SAP generally are made in several ways as in crosslinked polyacrylates. Crosslinking controls the nature of network of SAP and makes the polymer insoluble in water. Chemically, the major functional groups in polyacrylates are carboxylates. The carboxylates group will absorb water through hydrogen bonding. Other types of functional groups such as amides can also have hydrogen bonding with water. Using water soluble polymer, polyacrylamide, as an example (Figure 3) the polyacrylamide polymer chains once dissolved in water will have two types of hydrogen bonding, intra and intermolecular. The intramolecular hydrogen bonding tends to pull the individual molecular chain together, thus the individual polymer chain becomes folded and curled. The molecular volume of such polymer in water is small. The volume which the polymer chains occupy in aqueous solution, is called the hydrodynamic volume. The smaller the hydrodynamic volume, the closer the viscosity of polymer solution approaches that of water. In other words, the polymer's influence on the water is small if the hydrodynamic volume of that polymer is small. In the case of polyacrylamide, the

intermolecular hydrogen bonding also pulls the polymer chains together. Interestingly, polymer chains not only curl or coil by themselves, they also bundle together. The effective hydrodynamic volume of polyacrylamide is therefore low resulting in low viscosity. If the amide groups in polyacrylamide were hydrolyzed to carboxylate groups (i.e., the same functional groups in polyacrylates, or SAP), shown in Figure 4, intermolecular as well as intramolecular charge repulsion exist between polymer chains. These repulsions extend the hydrodynamic volume of polyacrylates and result in a much higher viscosity. In fact, some low molecular weight polyacrylates are used as thickeners due to this phenomenon. Carboxylates also have higher ability than amides in polyacrylamides to form hydrogen bonding with water molecules. Having numerous hydrogen bonding with water molecules, SAP absorbs and retains water into its matrix.



Volume or Size of a Non-Hydrolyzed Polyacrylamide Molecule vs. That of a Partially Hydrolyzed Polyacrylamide

Figure 4

At macroscopic level, the net result is an osmotic phenomenon. As shown in Figure 5, just as a reminder, sugar solution inside the collodion bag has higher solute concentration than that of the pure water outside the bag. The concentration gradient results in osmotic pressure gradient which drives water into the collodion bag. The sugar solution and collodion bag can be considered as the matrix of a SAP. Since SAP has many functional groups such as carboxylates (electrolytes) dissolved in water, the concentration of these groups is higher inside the SAP matrix. The concentration gradient results in osmotic pressure gradient. The osmotic pressure gradient between the network of SAP and surrounding aqueous fluid therefore, drives the water into the network of SAP.

The way the network of SAP is constructed has a great impact on the absorbency of SAP. The network of SAP is generally built via crosslinking of polymer chains.

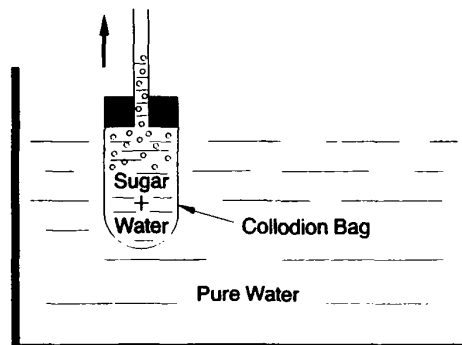


FIGURE 5. OSMOTIC PRESSURE

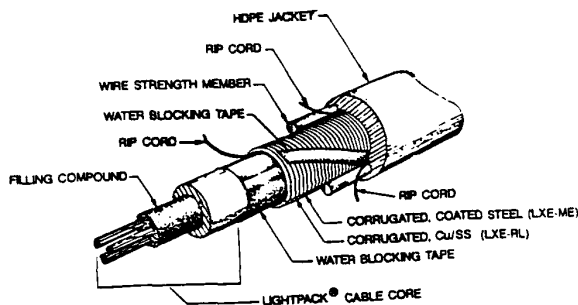
The amount of crosslinking is important and must be maintained at an optimum level depending on the application, such as the rate of absorption and total amount of water absorbed, for example. The crosslinking determines the space in the network of SAP, thus the total volume of SAP, which in turn influences the concentration of functional groups in the network. As mentioned before, concentration gradient affects the osmotic pressure gradient and thus the absorbency of SAP.

MATERIAL CONSTRUCTION

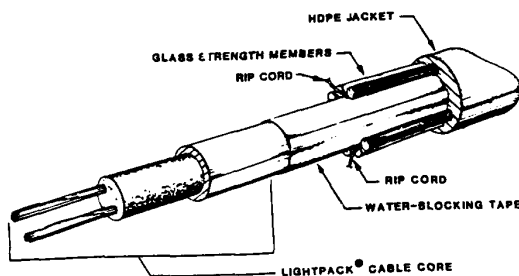
When incorporating SAPs into a cable design one must consider the ability of the SAP to quickly swell into a gel consistency and longitudinally block water paths along different sheath interfaces or within difficult to reach interstices. The ability of the formed gel to reactivate after drying is also critical. Three constructions were investigated; laminates that contain the SAP between two layers of nonwoven materials; coated SAP onto spunbonded nonwovens and onto synthetic aramid fibers; and SAP fibers which are made into yarns.

CABLE CONSTRUCTION

The incorporation of superabsorbents in optical fiber cables can best be explained by actual cable design. Figure 6 presents both a metallic and dielectric Lightguide Express Entry (LXE) optical fiber cables. In both designs, laminated SAP tapes are longitudinally applied in the sheath interface. In the metallic version the laminated SAP tape is located between the core tube and the corrugated armor, and an additional helically wrapped SAP laminated tape is introduced as insurance against the possibility of water migration along the metallic wires and the corrugated armor interface. In the dielectric version, the laminated SAP tape is located between the inner core tube and the outer jacket. These tapes prevent water migration within the cable in the event of a breach in the jacket due to rodents, lightning or accidental mechanical damage.

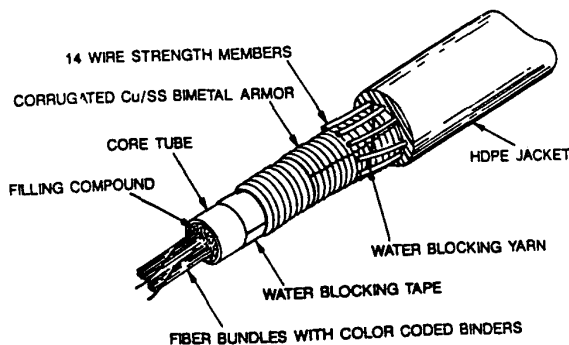


LXE-ME (Metallic) Sheath



LXE-DE (Dielectric) Sheath
Figure 6

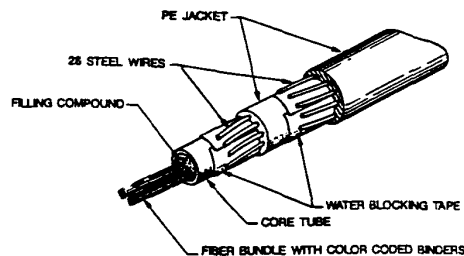
Figure 7 presents another SAP application in the form of a swellable yarn. The Primary Rodent Lightning (P-RL) optical fiber cable design incorporates a longitudinal laminated SAP tape between the inner core tube and the corrugated metal interface. It also contains a swellable superabsorbent yarn helically applied between the corrugated armor and the strength members, to prevent the possibility of water migration along this interface.



Primary Rodent-Lightning Sheath
Figure 7

Figure 8, presents another SAP application. In this Metallic Crossply optical fiber sheath design, it was important that the cable outside diameter not be increased with the introduction of the SAP tape. Therefore, the nonwoven spunbonded polyester tape originally used was impregnated with a SAP coating that impregnated the spunbonded matrix with only a one mil increase in the tape thickness. Since the tape remained compressible, there was no increase in the cables' outside diameter.

The scope of this paper does not allow for all the varied cable applications in both optical fiber and copper cables that have been successfully designed, and that are presently commercially available. However, the SAP material selection is vitally important and will next be discussed.



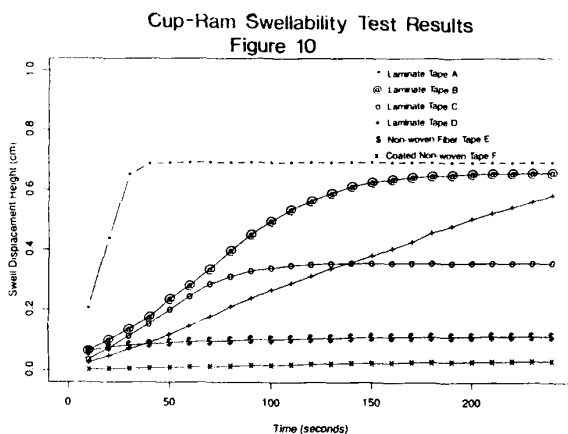
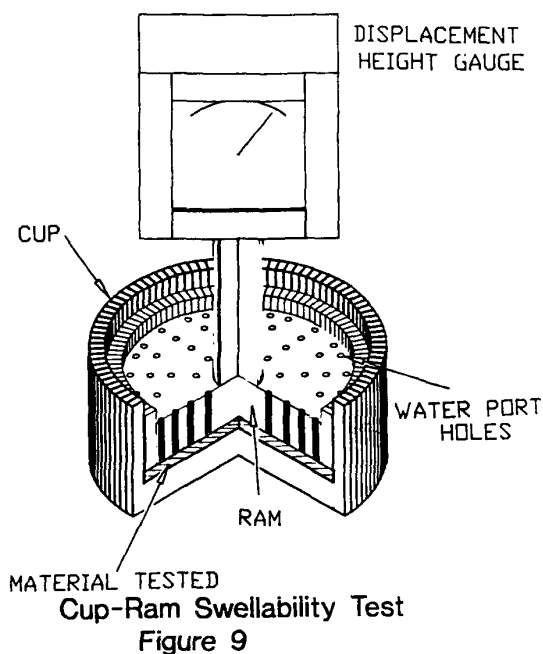
Crossply Sheath
Figure 8

MATERIAL SELECTION

The current commercial state-of-the-art SAP tests evaluate the material's absorbency or ability to absorb water, and are applicable for the incontinent market. For the cable industry a more straightforward approach is to measure a material's swellability in terms of swell height, rate-of-rise and gel retention.

The Lantor BV, Cup-Ram swellability test was modified to measure the effects of radial swelling. This test as seen in Figure 9, measures a material's swellability by monitoring the free vertical movement of a ram, as water is added to the cup. Figure 10 shows the swell displacement height in centimeters vs time in seconds for superabsorbent tapes. This test provides information on effects of different water types i.e., distilled-brackish-sea water, SAP loading and chemistry, carrier porosity-thickness-adhesion, as well as the effects of wetting agents and physical tape construction.

Figure 10 demonstrates the above effects using four similar SAP laminated tapes (A to D) from different manufacturers, as well as a SAP nonwoven fiber tape E and a SAP coated nonwoven tape F. The swellability of tape laminates A through D can be explained as one analyzes the individual components and tape structures.



The swellability of the nonwoven fiber tape E depends on the amount of layered swellable fibers per unit area. The swellability of the nonwoven tape F depends upon the amount of solids in the coating applied to the spunbonded nonwoven material. Although the swelling of the last two materials is not as impressive, swelling does occur within their matrix, and both have demonstrated exceptional gel retention.

These materials were also evaluated in a Hydraulic Pressure test. This test, while affected by the above characteristics, also measures the effects of a laminates' rate-of-rise and gel retention. While the product literature is full of different hydraulic pressure tests, the interpretation of results differs. It is therefore important to correlate the results to actual cable performance by dissecting the cable tested.

Table I shows the effects of tape thickness. The gap simulates the radial expansion within which the material is allowed to expand inside the cable, the travel represents the longitudinal migration due to a set pressure at the selected time in days and is a measure of gel retention. It should be noted that the travel length in Table I represents the maximum travel after one day, although the test was continued for a five day period.

Test Length- 30.5 cm Water Pressure- 1.0 meter				
Material	Thickness (cm)	Gap (cm)	Swell %	Travel @ 5 Days (cm)
Laminated tape A	.036	.102	283	10.6
Laminated tape B	0.25	.102	408	14.8
Laminated tape C	.025	.076	304	13.0
Laminated tape D	.033	.102	309	26.0
Nonwoven Fiber tape E	.071	.254	358	20.6
Coated Nonwoven tape F	.020	.064	320	13.3
#7 cc Swellable Yarn	759 Denier	.064		15.9
#1.67 cc Swellable Yarn	3183 Denier	.127		14.9
#.67 cc Swellable Yarn	7933 Denier	.254		16.8
Coated Aramid Yarn	2130 Denier	.064		14.8
Aramid/Swellable Fiber Yarn	2130 Denier/ 3183 Denier	.216		17.5
Coated Glass Roving	.102	.140	137	24.8

cc = cotton count

Comparing the matrix of the first four laminated tapes, the designer can make certain comparisons that would assist in material selection. i) Comparing tapes A & B, if the travel distance is deemed comparable, then tape B would be preferred because it is thinner, and has a higher percent (408% vs 283%) swell. ii) Comparing tapes B & C, if the travel length is deemed comparable, then tape B would be preferred since it has a higher percent swell. iii) Tape D is considered the worst performer on the basis of it's longer water migration (26 cm.), even though its' 309% swell is comparable to tapes A and C.

Tapes E and F are not laminates; E is a nonwoven SAP fiber tape, while F is an SAP coated spunbonded nonwoven tape. Both tapes perform well considering their thicknesses and gap constraints. It should be noted that compared to the results in figure 10, these two materials show better performance than anticipated. This underscores the value of understanding test results and their relevance to the application under investigation.

The SAP swellable yarns were evaluated in three different sizes and in combination with an aramid fiber for added strength. Also, SAP coated aramid and glass rovings were evaluated, and although having lower percentage swell, they had comparable gel retention to SAP tapes.

It should be noted that changes in SAP loading, type chemistry, gap size, water pressure and duration will change these results. However, these results are indicative of the expected performance in actual cable designs.

IMPACT

Presently, all of our outside plant optical fiber cables have one or two types of SAP waterblocking materials, with maintenance free performance over the last five years. These materials are also making inroads into copper outside plant products. Also, additional applications are being discovered for SAPs such as in foams and compounding into elastomers. They've even been compounded into filling compound for added performance. It is clear that superabsorbents present a whole new generation of materials in providing maintenance free water blocking provisions in cable design. What is needed is a set of industry standards to assist cable designers in selecting and implementing these superabsorbent materials.

CONCLUSIONS

The use of superabsorbents present a radical departure from the traditional means of providing water blocking in cable design. An attempt at explaining the physical and chemical mechanisms of SAPs has been presented. Also bench-type tests to evaluate material performance have been outlined. Additionally, since SAP materials are compatible with all other cable processing materials, the ease of manufacturing presents yet another attribute not discussed in this paper. Tests have been developed to evaluate the performance of these materials and cables dissected to ascertain correlation with these results. As a result, all of our outside plant optical fiber cables, over the last five years have been designed with one or two types of superabsorbent materials.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the many contributions from members of AT&T Bell Laboratories and AT&T Network Cable Systems.

REFERENCES

1. Obenski, B. J., *New Developments in Super-Absorbents in the United States, Europe and Japan, Proc. pp 1-2, INDA-TEC (1986).*
2. R. E. Erickson, *Proc. Absorbent Prod. Conference, Sect. VI (1980) U/TS, Kalamazoo, Mich.*
3. J. R. Gross, "The Evolution of Absorbent Materials," p. 3, *Absorbent Polymer Technology*, Ed. Lisa Brannon-Peppas and Ronald S. Harland, Elsevier (1990).



John Arroyo joined AT&T Bell Laboratories in Whippany, New Jersey in 1969, and has worked in research and development of copper and fiber optic cables at Norcross, Georgia since 1978. As a Member of the Technical Staff, his responsibilities include fiber optic cable development concepts, sheath design, standardization of lightning tests and cable specifications. John received the Design News Journal "Excellence in Design Award" in 1981, for a "Helical-Wrap Peel Strength Test". He co-authored the "Outstanding Technical Paper", at the 30th IWCS, November, 1981, and received the 'Fiber Optic Award' from AT&T International in July, 1990, for his contributions in fiber optic technology. John has co-authored seven technical papers and received seventeen patents related to cable design.



Jim Sheu joined the Materials Engineering Department at AT&T Bell Laboratories in Norcross, Georgia in 1990. He is responsible for the research and development of materials including water blocking materials, used in fiber optic cables and apparatus.

Dr. Sheu received his M. A. and Ph. D. degrees in Chemistry from Rice University in 1973 and 1975 respectively. He did postdoctoral research at Harvard University on a fellowship. His areas of research included synthesis and application of superabsorbent polymers, water soluble polymers and specialty chemicals. In 1984, he also taught graduate chemistry courses at the University of Houston.

Dr. Sheu is a member of American Chemical Society and Society of Petroleum Engineers.